LINEAR INVERSION OF GPS DATA OF THE 2009 L'AQUILA EARTHQUAKE BY MEANS OF A HIGH RESOLUTION 3D FINITE ELEMENTS APPROACH

Istituto Nazionale di Geofisica e Vulcanologia

Manuela Volpe, Antonio Piersanti, Daniele Melini, Emanuele Casarotti
Istituto Nazionale di Geofisica e Vulcanologia, Roma
manuela.volpe@ingv.it; antonio.piersanti@ingv.it; daniele.melini@ingv.it; emanuele.casarotti@ingv.it

S43A-2027

work submitted to GJI

INTRODUCTION

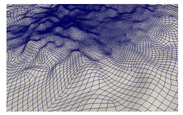
The 2009 L'Aquila earthquake (Ml=5.8,Mw=6.3) occurred on April 6th at 01:32 UTC in the Central Appennines at a depth of about 9.5 km and was felt all over the central Italy. The main shock was preceded by a long seismic sequence started several months before and was followed by thousands of aftershocks, some of them with Mw>4.
In this work we present a 3D Finite Element (FE) investigation of the slip distribution on the fault by linear inversion of GPS data. Our approach is based on a fully 3D parametrization of the spatial domain by means of a high resolution hexahedral mesh honouring topography and small scale heterogeneities.

THE 3D MODEL

We built up a high-resolution 3D model, ~20 km thick, spanning a surface of about 13500 km^2 in the Central Italy.

Real surface topography having 500 m spatial resolution, obtained from SRTM 90 m digital elevation data, was incorporated within the model.

The volume was discretized using 20-nodes brick elements. The generated unstructured mesh contains 1461474 elements, resulting in 5933380 nodes. The horizontal element size is biased from 300 m to 2-3 km using the paving meshing algorithm in combination with an appropriate adaptive sizing function. The vertical size is fixed at 300 m.



A detail of the mesh biasing

The rheological properties were deduced from a vp and vp/vs travel time tomographic model[1]. The nearest neighbor interpolation method was used to include tomography within the simulation domain.

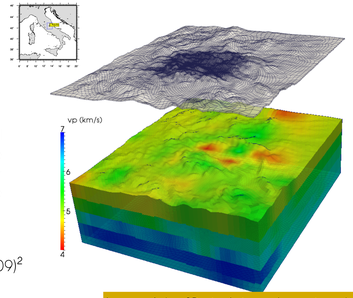


Image of the 3D simulation volume viewed from SW. The compressional wave velocity and the FE mesh are shown. Topographic reliefs have been enhanced for a better visualization.

We adopted the seismic source geometry as modeled by Atzori et al. (2009)[2]

FIXED SOURCE PARAMETERS:
STRIKE=133°
DIP=47°
RAKE=-103°
LENGHT=20 km, WIDTH=14 km

[1] Chiarabba et al., Earth Plan. Sci. Lett. (2010)
[2] Atzori et al., GRL (2009)

COMPUTATIONAL TOOLS

The model was built and meshed by means of CUBIT, from Sandia National Laboratories (http://cubit.sandia.gov/index.html), a powerful and full-featured software toolkit for robust generation of 2D and 3D FE grids and geometry preparation.

The FE simulation was carried out by FEMSA, a recently developed FE simulation tool[1]. It is based on CalculiX, (http://www.calculix.de/), a free package designed to solve field problems.

M. Volpe, D. Melini, A. Piersanti, Annals of Geophys. (2007)

The main features of simulating with FEMSA are:
- the seismic source is implemented as a suitable distribution of double couples of forces
- arbitrary fault geometry and slip distribution are allowed
- inhomogeneous boundary conditions are applied by prescribing analytically computed displacements to the edge nodes (Okada model).

INVERSION STRATEGY

The fault plane was subdivided in 70 patches 2km x 2km
The Green functions were computed through FE simulations
The Dumped Least Squares method was used to invert for the slip

$$\mathbf{d}_{est} = \mathbf{d}_0 + \left(\mathcal{G}^T \cdot \mathcal{W} \cdot \mathcal{G} + \mathbf{k}^2 \cdot \mathcal{D}^T \cdot \mathcal{D}\right)^{-1} \cdot \mathcal{G}^T \cdot \mathcal{W} \cdot \left(\mathbf{u}_{obs} - \mathcal{G} \cdot \mathbf{d}_0\right)$$

We inverted GPS data both assigning 0 or 0.5 weight to the vertical components of the co-seismic displacements.

The data fit quality is estimated in terms of Weighted Root Means Squares:

$$\mathbf{WRMS} = \sqrt{\frac{\sum_i^N \left(\frac{u_{i,mod} - u_{i,obs}}{\sigma_i}\right)^2}{\sum_i^N 1/\sigma_i^2}}$$

The computed WRMS refers to the 2D (horizontal) deformation pattern when we inverted the horizontal displacements alone and to the 3D deformation pattern when we included vertical components

INVERSION RESULTS

We used GPS data from
Anzidei et al., GRL (2009) ---> A09
Cheloni et al., GJI (2010) ---> A10
and built up 6 datasets:

GPS17 → 12 permanent sites + 5 survey CaGeoNet sites installed 4 days before the main shock (CADO, CPAG, ROIO, SELL, SMCO) from A09
GPS31 → 26 permanent sites + 5 survey CaGeoNet sites from C10
GPS26 → 26 permanent sites from C10
GPS45 → 26 permanent sites + 5 survey CageoNet sites + 14 survey sites installed after April 6th from C10
GPS31+2 → same as GPS31 + 2 permanent sites from A09 (MTTO, VVLO)
GPS17+16 → same as GPS17 + 16 permanent siets from C10
} merged datasets

For each dataset, we inverted with
$\mathcal{W}_{vert} = 0$ FIRST ROW OF PICTURES
$\mathcal{W}_{vert} = 0.5$ SECOND ROW OF PICTURES

The predicted horizontal displacements are in very good agreement with the measured co-seismic deformation field, as confirmed by the small values of the WRMS (2-4 mm).
The estimated rupture model is quite stable for all of our inversions and is overall consistent with previous analyses carried out with homogeneous[1] or layered[2] domains. Nevertheless, whereas simple half-space or 1D models obtain a complex slip on the fault, the introduction of 3D complexities provides a more concentrated slip distribution pattern on the rupture plane, evidencing a single area of high slip release. We remark that this is a robust common feature of all our inversions. Therefore, we conclude that the adoption of a realistic 3D domain has a marked impact on the retrieved source model, showing that homogeneous or layered approaches are likely to introduce some trade-off between (not honoured) domain complexities and source details.

[1] Atzori et al., GRL (2009); Cheloni et al., GJI (2010)
[2] Cirella et al., GRL (2009); Scognamiglio et al., SRL (2010)